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ORIGINAL ARTICLE

Cleaning ability and induced dentin loss of a magnetostrictive ultrasonic instrument at different power settings

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Abstract Some laboratory studies have evaluated the oscillation mode of ultrasonic scalers. None of them recorded its influence on calculus removal and quantified dental hard tissue loss. This study aimed to compare the performance of a magnetostrictive ultrasonic instrument at different power settings in vitro in relation to the tip oscillation activity. The oscillation activity of the straight Slimline® insert in the Cavitron® ultrasonic scaling device was analyzed at five different power settings with the help of two laser vibrometers. The performance of this instrument was tested on 60 roots of human single-rooted teeth. Twelve roots each were randomly assigned to be instrumented at a given power setting. Every root was instrumented for 120 s at a standardized instrumentation force of 0.1±0.05 N. In addition, another 30 periodontally involved roots with subgingival calculus were instrumented accordingly to assess the calculus removal potential. The surface characteristics after instrumentation were analyzed under scanning electron microscope. The instrumentation at minimum power setting resulted in an mean increase of the root surface roughness of 0.18±0.28 compared to 0.51±0.48 at maximum power setting (P=0.0327). The loss of dental hard tissue amounted to 11.37±3.64 at minimum compared to 23.37±15.76 at maximum power (P=0.0010). The higher the power setting, the more calculus was removed. The values of the latter ranged between 4.04±1.87 and 11.26±4.66 mm^2 of cleaned dentin surface area (P=0.0065). At lower power settings, a more favorable relation between cleaning ability, loss of dentine, and surface roughness was found.

Keywords Ultrasonic scaler · Dentine loss · Surface roughness · Calculus · Oscillation analysis · SEM

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Introduction

The removal of plaque and calculus from tooth surfaces with ultrasound is achieved primarily by a vibratory machining action of the instrument tip, supported by cavitational activity [1] and acoustic microstreaming within the associated cooling water supply [2]. The efficiency of the machining action, as well as the cavitational activity, is directly related to the displacement amplitude of the instrument tip [3, 4].

Elliptical motion was demonstrated for piezoelectric and magnetostrictive ultrasonic devices [5–7], and various factors influencing the movements have been identified, for example, loading and wear of the probe tip [8], generator power and probe cross-section, or amount of cooling water [6]. At low and medium power settings, the displacement amplitude of the tip was reduced by increased water flow. Only at high power settings the water left the instrument as a jet and left the tip itself unconstrained [9]. This variability shows that the arbitrary linear scale of the control dial is a poor indicator of the tip action.

A systematic review by Tunkel et al. [10] failed to show superior clinical results for either power-driven or manual debridement, while the power-driven approach required less treatment time. Later reviews confirmed these results for power-driven instruments with new designs [9].

A study by Drisko [11] supplied sufficient scientific evidence to support the clinical use of the modified inserts (EWP-12 L+R) for the Cavitron®/TM ultrasonic device (Dentsply International, York, PA, USA). The performance of the modified ultrasonic inserts in comparison to the standard ultrasonic inserts for the Cavitron ultrasonic instrument was the subject of a study by Dragoo [12]. The results showed that the modified inserts produced less damage on the root surface and removed more calculus than the standard ultrasonic inserts or hand instruments. The modification of the ultrasonic inserts resulted in an improved tactile sensation over hand instruments, which was also better than that achieved with the standard inserts. Also, the penetration of a water irrigant into deep pockets was improved compared to the other two instruments.

Flemmig et al. evaluated the defect depth and the defect volume of root surfaces which had been instrumented with a piezoelectric and a magnetostrictive ultrasonic device [13, 14]. The results showed that the defect depth and the defect volume increased with the tip angulation, applied lateral force, and higher power setting. The magnetostrictive ultrasonic instrument consistently produced deeper and more voluminous defects than the piezoelectric ultrasonic instrument.

Although a large variety of ultrasonic scalers are presently in use in dental offices, there is no accepted method for quantifying the power output of these devices. Most of them are equipped with control dials, which enable the operator to vary the amount of electrical power input to the transducer. The aim of the present study was to obtain an overall impression of the cleaning ability versus the damaging potential of the different power settings of the Cavitron® ultrasonic device at different power settings. For this purpose, the performance of a magnetostrictive ultrasonic instrument at different power settings was evaluated and the damaging potential of the respective power settings to the root surface was identified by evaluating the substance removal and surface roughness potential. The null hypothesis was that there was no difference in the latter parameters when compared at different power settings.

Materials and methods

Oscillation analysis

The Cavitron® Jet SPSTM ultrasonic device (Dentsply International, York, PA, USA) with the straight Slimline® insert was secured by a clamp at the middle of the instrument's handle. The clamp was attached to a positioning device (Fig. 1). Special attention was paid to secure the instrument handle at a defined distance to the instrument tip. The positioning device was used to move the instrument tip into the focus of two single-point laser vibrometers (Polytech OFV 303 Sensor Head) which measured the tip movements in the transverse axis and in the longitudinal axis of the instrument. Both vibrometers were attached to a controller (Polytech OFV 3001 Vibrometer Controller), which transduced the information to an oscilloscope (Le Croy 9350 AL 500 MHz). The test setup is depicted in Fig. 1. After each measurement, the data were saved on a computer and analyzed (Generic Waveform Reader, LabVIEW TM 5.1, National Instruments). With the help of the program MATLAB (The Math Works, Inc., Version 6.0.0.88), the oscillations were depicted in a diagram and the inherent frequencies were determined by means of a Fourier analysis.

Six new straight Slimline® inserts were measured at five power settings each (minimum, one quarter, medium, three quarter, and maximum power setting) resulting in 30 single measurements consisting of a longitudinal and a transversal component.

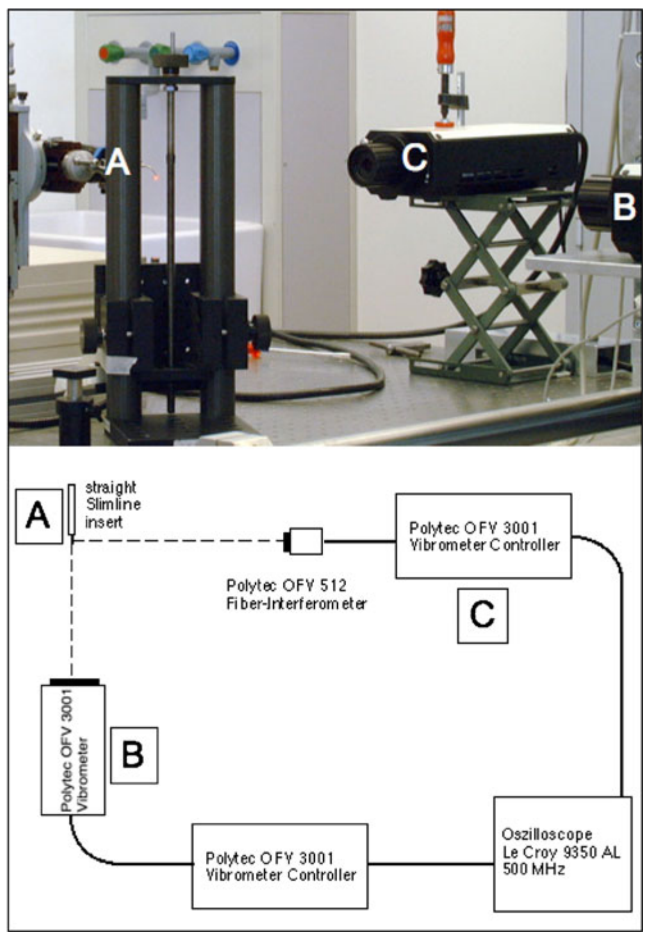

Fig. 1 Test setup for the vibration analysis (*A* ultrasonic insert in the fixation device, *B* vibrometer, *C* vibrometer controller)

Specimen preparation and instrumentation

Sixty roots of human single-rooted teeth were used for the experiments. After extraction, roots were cleaned with a M 23 A universal hand curette (Deppeler, Rolle, Switzerland) and the crown was separated from the root with a diamond cut-off wheel 230 CA (Merck Schweiz AG, Dietikon, Switzerland). Only one surface from each root was selected for the experiment, deliberately excluding extreme grooves, restoration margins, or the cementoenamel junction. A rectangular area of interest was identified and was outlined with a diamond-coated disk (Intensiv, Swiss Dental Diamond, Discoflex, 173 D) in a slow contra angle (Micro Mega, Genève-Acacias, Switzerland) with water cooling. Impressions were taken using an addition-type polyvinyl siloxane of low viscosity (President light body, Coltène AG, Switzerland) and replicas (Stycast® 1266, Emerson & Cuning, Switzerland) of these areas of interest were cast and allowed to set for 24 h. Between the experiments, roots were stored in water or in a humidity chamber.

The roots were reversibly fixed to the bottom of a glass vessel using an addition-type polyvinyl siloxane (President light body, Coltène AG, Switzerland). The vessel was filled with 40 ml of distilled water and placed on a pressure-sensitive electronic device (TM 503 Power Module, Tektronix®, Beaverton, Oregon, USA) in order to apply a standardized instrumentation force of 0.1±0.05 N.

Five different power settings were selected on the control dial of the Cavitron®/TM Jet SPSTM ultrasonic device (Dentsply International, York, PA, USA). Due to the design of the control dial, these positions were easily reproducible to make sure the same voltage was applied to the instrument:

(a) minimum power setting,
(b) one quarter power setting,
(c) medium power setting,
(d) three quarter power setting,
(e) maximum power setting.

Twelve roots were then randomly assigned to one treatment group and were instrumented at one of these power settings. Every root was instrumented for 120 s. The Slimline® insert which showed the most pronounced tip movements was used for the instrumentation process. An effort was made to use the ultrasonic inserts according to the manufacturer's directions, i.e., the operator performed the working strokes perpendicular to the root axis with a tip angulation of 0°. As in the clinical situation, the axis of the insert was positioned parallel to the long axis of the root.

Loss of tooth substance determination

After the instrumentation described above, the water was collected and the vessel was rinsed with more distilled water to remove all dentine particles. The solution was diluted with 10.0 ml HCl 25% and 10.0 ml of Sr_2Cl_2 2.5%. Distilled water was added until the solution amounted to 100.0 ml of liquid. These specimen solutions were placed in an ultrasonic bath for 30 min to dissolve insoluble dentine particles and to avoid precipitation. The amount of calcium in the specimen solutions was determined by atomic absorption spectrometry (AAS) at 422.7 nm. The spectrometer was calibrated with standard solutions containing 0.4 to 10.0 µg of calcium. The content of calcium in the specimen solutions with respect to the dilution was calculated according to this calibration curve.

According to the literature, dentine contains 27% calcium [15]. Consequently, the absolute loss of tooth substance was calculated and put in relation to the size of the instrumented surface resulting in the loss of tooth substance per square millimeter of instrumented root surface.

Evaluation of surface roughness

The instrumented root specimens were removed from the glass vessels and were washed and dried. Impressions were taken using an addition-type polyvinyl siloxane of low viscosity (President light body, Coltène AG, Switzerland) and replicas (Stycast® 1266, ICI Belgium N.V., Westerlo, Begium) of the areas of interest were cast. These were horizontally glued on scanning electron microscope (SEM) mounts (Baltec AG, Balzers, Fürstentum Liechtenstein) with superglue (Renfert Sekundenkleber, Dentex AG, Zurich, Switzerland). The replicas of the area of interest before and after instrumentation were then assessed for surface roughness. Measurements were made with a precision profilometer (Form Talysurf-50, Rank Taylor Hobson, Leicester, UK). The root surface was traced with a stylus with a 60° angle (60°-Kleinbohrungstaster WIB 60, ELYT Spezial) and 12 mm length. The vertical displacements were electronically converted and a profile was produced by the computer on the monitor. The computer calculated the arithmetic average of the surface roughness (Ra). The surface replicas were analyzed consecutively before and after the experiment, starting with tooth number 1 through to number 60. The examiner was blinded to the coding. Measurements were taken vertically and horizontally to the root axis, resulting in four measurements per root specimen. The profilometric readings were repeated five times for each experimental surface. The measurements were confined to the area of interest where the first reading started 1 to 2 mm coronal from the apical extent and 0.5 to 2 mm inside the lateral extent of the area of interest. The starting point depended on the size of the demarked area. The consecutive readings always ran parallelly to the first reading, but were displaced coronally between 0.5 and 2 mm according to the allowed space. Therefore, it was attempted to gain an overall impression of the entire surface roughness. A further attempt was to measure the surface roughness at the same positions before and after the experiment by documenting the exact displacement of the stylus for each individual reading for each surface on the initial replica and applying the exact same coordinates on the postexperimental replica. The length of the profilometric reading path was generally 3 mm.

Calculus removal potential

Another 30 single-rooted human teeth with subgingival calculus were collected. Only one surface from each root was selected for the experiment, deliberately excluding extreme grooves, restoration margins, or the cementoenamel junction. Again, a rectangular area of interest was identified and was outlined with a diamond-coated disk (Intensiv, Swiss Dental Diamond, Discoflex, 173 D) in a slow contra angle (Micro Mega, Genève-Acacias, Switzerland) under water cooling. The roots were horizontally glued on SEM mounts with acrylic resin (PalaDur®, Heraeus Kulzer GmbH, Wehrheim, Germany) with the area of interest facing the top. Impressions were taken using an addition-type polyvinyl siloxane of low viscosity (President light body, Coltène AG, Switzerland) and replicas (Stycast® 1266, ICI Belgium N.V., Westerlo, Begium) of the areas of interest were cast. Between the experiments, the roots were stored in water or a humidity chamber.

The experiment was carried out on a pressure-sensitive electronic device (TM 503 Power Module, Tektronix®, Beaverton, Oregon, USA) so that the applied instrumentation force could be standardized to 0.1±0.05 N. The instrumentation time was restricted to 60 s to resemble the clinical situation. As in the previous experiment, an effort was made to use the ultrasonic inserts according to the manufacturer's directions, i.e., performing the working strokes perpendicular to the root axis with a tip angulation of 0°.

For the purpose of calculus determination, a specially designed computer program was used (PPK, Zurich, Switzerland). This program is used in our laboratory to express the cleaning effect (Re) of toothpaste or toothbrushes. Gutjahr [16] described the exact methodology. The only small modification to the program to be applied to this study was that the computer had to recognize the light tooth surface as clean. Therefore, the computer with this software could automatically determine the amount of calculus present on the tooth surface through the contrast with the light background. Because the program relies on contrast in black and white, the color images were converted into gray pixels. The demarked area of interest on each tooth was cut out digitally along the lines cut with the diamond disk, using the mouse and the crosshair icon. The isolated surface was processed with this special program so that the surface area of calculus present could be determined and expressed as a percentage of the entire surface area. In this way, the amount of calculus on the area of interest before and after instrumentation could be determined.

SEM analysis

The replicas were further analyzed under the SEM (Amray 1810 T, Amray, Bedford, MA, USA). They were gold-sputtered with a sputtering device (Sputter SCD 030, Baltec AG, Balzers, Liechtenstein) and examined for structure loss and the amount of cementum still present, damage, scratches, gouges, cracks, and possible debris. Overview micrographs were taken of the area of interest at a magnification of ×24.6.

Statistical analysis

The statistical analysis was done with a commercially available statistics computer software (StatView® 4.02, Abacus Concepts, Berkeley, CA, USA). The results were graphed in box plots. Normal distribution was tested using a Kolmogorov–Smirnov test. Kruskal–Wallis one-way test of variance followed by Mann–Whitney test for individual comparison were used. Bonferroni adjustment was applied for multiple testing. For all statistical analysis, the level of significance was set at 5%.

Results

Oscillation analysis

Figure 2 shows the mean amplitudes of the instrument tip at the different power settings. Amplitudes in the long axis of the ultrasonic instrument are shown in light gray and amplitudes in the transverse axis in dark gray. The average amplitude in the long axis of the instrument decreased with the power input, whereas the highest average amplitude in the transverse axis of the instrument was registered at medium and three quarter power settings.

Tooth substance loss

The loss of dental hard tissues is presented in Fig. 3. The least calcium loss was determined at minimal power setting and was significantly lower compared to values obtained at medium and maximum power settings (P=0.0039 and P=0.0010, respectively). Thus, the null hypothesis for these settings was rejected. The other intermediate power settings (one quarter, three quarter) did not show any statistically significant differences ($P \geq 0.05$).

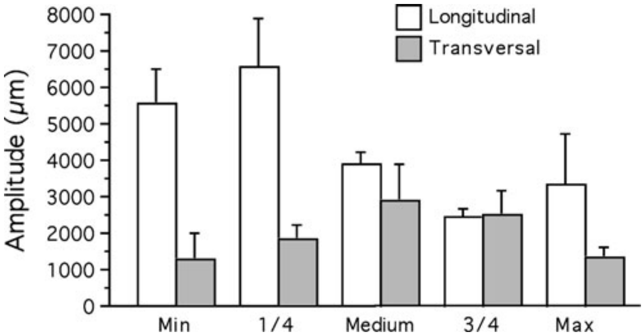

Fig. 2 Amplitudes of the instrument tip at different power settings

Surface roughness

The differences in surface roughness (mean of longitudinal horizontal measurements) are shown in Fig. 4. The mean values are positive figures indicating that the surface roughness increased due to the instrumentation. The instrumentation at minimum power setting resulted in significantly less roughening of the surfaces compared to maximum power setting (P=0.0327). The comparison between the other groups shows a tendency towards a continuous increase in Ra with the power input. Due to the high standard deviations and small differences, these differences are not statistically significant after multiple comparisons ($P \geq 0.05$).

Calculus removal

Figure 5 shows the calculus removal represented in square millimeters of removed calculus per minute at a given power setting. The null hypothesis was rejected as the instrumentation at three quarter and maximum power settings cleaned a significantly bigger area per minute compared to the minimum power setting (P=0.0065). The other groups did not show significant differences ($P \geq 0.05$).

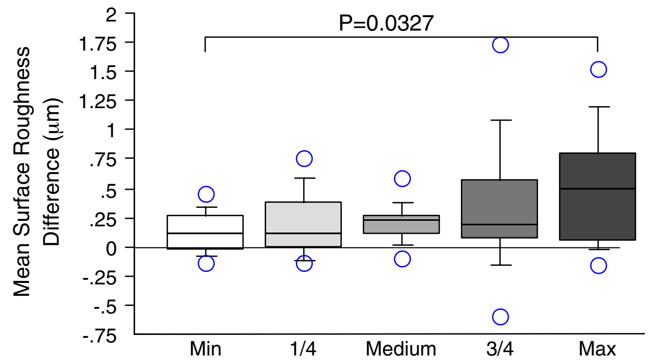

Fig. 4 Mean difference of the cumulative root surface roughness (Ra) between values obtained before and after instrumentation at different power settings. Box plot illustration (*horizontal bars* medians, *boxes* interquartile areas, *error bars* tenth and 90th percentiles, *dots* extreme values). Significant differences are marked with an *asterisk* (Kruskal–Wallis and Mann–Whitney tests with Bonferroni correction; $P<0.005$)

SEM analysis

Figure 6 shows the typical specimens before and after instrumentation.

Before instrumentation, the roots exhibited a smooth surface with flattened areas corresponding to the strokes of the hand curette, which was used to clean the roots (Fig. 6a, c). Sometimes, gouges or small scratches could be seen, running parallel to the long axis of the root, in the same orientation as the strokes of the hand instrument (Fig. 6a).

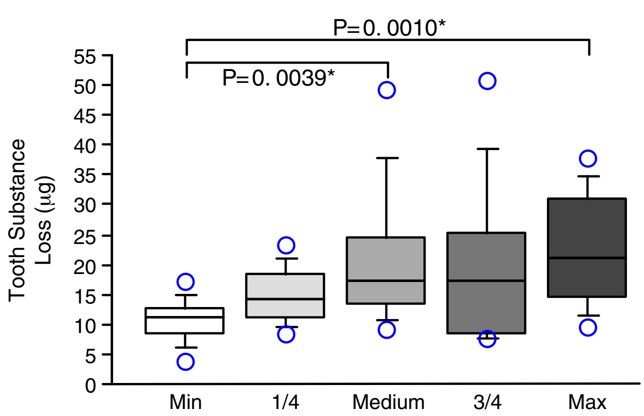

Fig. 3 Loss of tooth substance after instrumentation at different power settings. Values in micrograms of dental hard tissue per square millimeter of instrumented surface; instrumentation force=10±5 g, instrumentation time=120 s. Box plot illustration (*horizontal bars* medians, *boxes* interquartile areas, *error bars* tenth and 90th percentiles, *dots* extreme values). Significant differences are marked with an *asterisk* (Kruskal–Wallis and Mann–Whitney tests with Bonferroni correction; $P<0.005$)

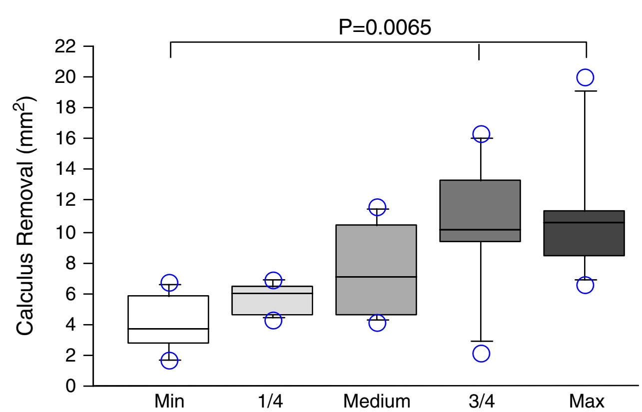

Fig. 5 Calculus removal at different power settings. Values in square millimeters of cleaned root surface; applied instrumentation force=10±5 g, instrumentation time=60 s. Box plot illustration (*horizontal bars* medians, *boxes* interquartile areas, *error bars* tenth and 90th percentiles, *dots* extreme values). Significant differences are marked with an *asterisk* (Kruskal–Wallis and Mann–Whitney tests with Bonferroni correction; $P<0.005$)

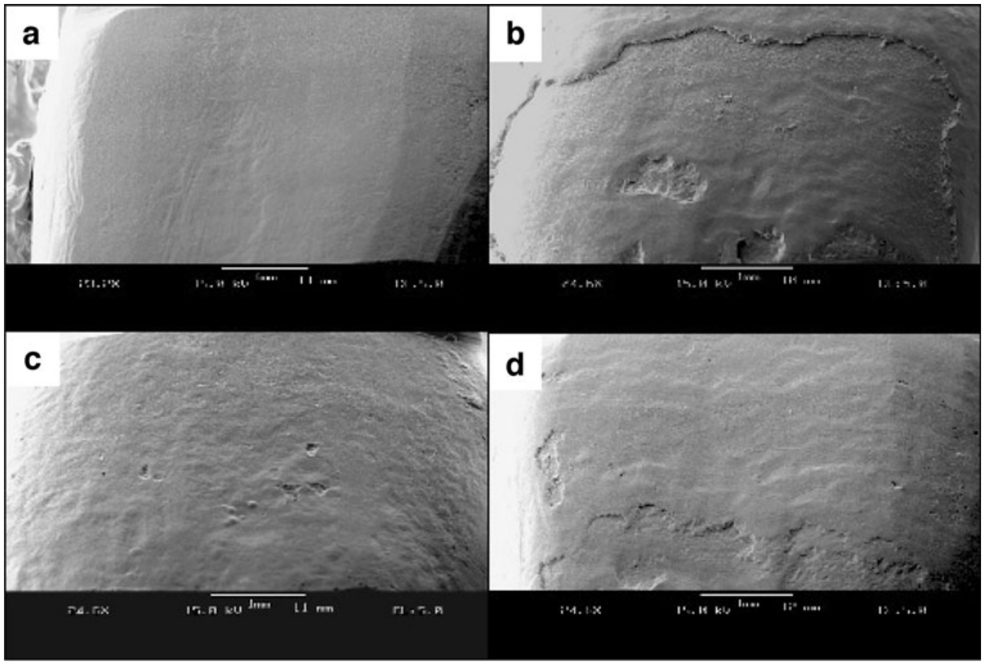

Fig. 6 Representative SEM images at a magnification of ×24 before (*left*) and after (*right*) instrumentation. The *bar* represents a distance of 1 mm. Before instrumentation, flattened areas, gouges, and scratches without undulatory patterns were observed (**a**, **c**). After instrumentation, undulatory patterns of scratches (**b**) and pits in the same orientation as the instrument strokes were observed (**d**)

Very rarely areas could be seen where the cementum had been completely removed (Fig. 6b, d).

After the instrumentation, the ultrasonic instrument left undulatory patterns of scratches and pits where partial or complete layers of tooth substance seemed to be removed (cementum; Fig. 6b, d). The higher the applied power input was, the larger and deeper these defects were. The orientation of the pits corresponded to the instrumentation strokes of the ultrasonic tip (Fig. 6d).

Discussion

In this study, five different power settings of the Cavitron ultrasonic device with a straight Slimline insert were compared and related to their performance. The parameters were loss of tooth substance, surface roughness, and calculus removal. The movements of the instrument tip at every power level were analyzed with the help of laser vibrometers to provide an insight into the function of the ultrasonic instrument and to correlate the tip movement with the in vitro outcome. Selected root specimens were examined under SEM. Our null hypothesis was rejected because there was significantly more loss of tooth substance at medium and maximum power settings and a significant increase in surface roughness at maximum power setting.

The oscillation analysis showed that the amplitude along the long axis of the instrument decreased when the power was increased from one quarter to three quarter. A study by Lea [17] showed that a linear increase in displacement amplitude was more likely to be found, the larger and heavier the tested ultrasonic tips were. The lighter tips were more likely to be influenced by the various factors listed above. Due to a lower rigidity, these tips are more prone to vary in amplitude as well as in orientation of the oscillation. Particularly, the Slimline demonstrated a greater degree of elliptical motion than the heavier tips [6]. So we might conclude that the greater degree of roughness and loss of dentine is a result of the lateral oscillation component rather than of the power setting alone.

According to an investigation in Switzerland by Imfeld and Lutz [18], 42.6% of patients visit the dental hygienist at least once a year, 23.9% even twice a year for maintenance of oral hygiene. Thus, the removal of dental hard tissue must be as low as possible not to put these patients at risk of irreversible tooth damage, hypersensitivity, or in extreme cases, loss of vitality or tooth fracture. In addition, recent studies have shown that extensive removal of “diseased” root cementum is not necessary for the successful treatment of periodontitis during active periodontal therapy. Nakib et al. [19] failed to prove penetration of endotoxins into the cementum of periodontally involved teeth. Nyman et al. [20] carried out periodontal surgery in a split-mouth design in a beagle model. On one side of the jaw, the roots were instrumented with curettes and a diamond bur, whereas on the contralateral side, they were only cleaned with rubber tips and cups and a polishing paste with low abrasiveness. Histologically, the healing showed similar results on both sides. Consequently, the instrumentation of the root surface in recent years has become more and more conservative and the amount of hard tissue removal of the respective instruments has become an important issue in periodontal literature.

Under the conditions of the present investigation, the use of ultrasonic instruments at lower power settings should, therefore, be preferred. This result is in accordance with the study of Flemmig and coworkers [13, 14] who found that the applied lateral force had the greatest effect on the defect volume followed by the chosen power setting and the tip angulation. The study of Ritz et al. [21] also found a more pronounced tooth substance loss with increasing instrumentation forces in the range of 100–400 p was found. The latter study suggested a force of 100 p to be used for ultrasonic instruments.

In the present study, a very low application force of 0.1 ± 0.05 N was chosen (0.1 N=10 g=10 p). This light force provides the operator with a good tactile sense, which is needed during clinical application. A tip angulation of 0° was chosen, which caused the least defect depth and volume according to the study of Flemmig et al. [13, 14] and which is recommended by the manufacturer of the Slimline® modified insert (Dentsply International, York, PA, USA).

Due to the delicate testing procedure of the present investigation, an effort had to be made to collect enough liquid for the AAS and to intensify the differences in calcium loss between the groups. The roots were instrumented for 120 s because this appeared to be a sensible instrumentation time per tooth surface assuming a heavily calculus-infected site.

The aim of root instrumentation among others is the efficient removal of plaque deposits and calculus and the creation of a smooth surface [22]. Although the roughness of the root surface does not seem to interfere with periodontal healing, the diagnosis of remaining subgingival calculus on a rough root surface might be hampered [23]. Consequently, an instrumentation method which creates rough dentine surfaces carries the risk of overinstrumentation on one hand and remaining undiagnosed calculus on the other hand. A study of Leknes et al. [24] showed that the microbial recolonization of intentionally roughened root surfaces occurred more rapidly than the recolonization of smooth surfaces debrided with a sharp hand curette. The present study used root specimens instrumented with hand curettes because the roughness data of untreated roots would have shown a much bigger variability. After ultrasonic instrumentation, an increase in roughness was found throughout the specimens, which is in agreement with the results found by Schmidlin et al. [25]. In this study, the hand curette is used as the gold standard of debridement techniques, which achieves a mean Ra of 0.60 on bovine dentine, whereas the instrumentation with the magnetostrictive ultrasonic device (Cavitron/Slimline) results in a mean Ra of 0.90. The instrumentation time in this study was also 120 s. The applied instrumentation force was slightly higher (0.4 N).

Another study by Santos et al. [26], however, contradicts these findings. This in vivo comparison found significantly rougher surfaces after hand curette treatment than after ultrasonic treatment. The experimental teeth of this study were designated for extraction and, therefore, the scaling conditions were probably less than ideal compared to the bovine dentine specimens used in the study cited above.

The micromorphological evaluation showed especially at higher power levels that complete layers of tooth substance had been removed and that these defects ran parallel to the instrumentation strokes, which were perpendicular to the root axis (Fig. 6a). In addition, undulatory patterns of scratches were observed, showing the same perpendicular orientation. This pattern of pits and scratches could explain why the average surface roughness was higher when the stylus ran parallel to the long axis of the roots than when the stylus ran perpendicular to the long axis of the roots. The orientation of the pits and scratches could account for the stylus being exposed to bigger vertical displacements resulting in a higher average surface roughness.

According to the tooth substance loss, the calculus removal potential increased with increasing power settings, which may reflect a greater aggressiveness of the instrument tip with increasing energy. However, in this part of the study, the instrumentation time had to be restricted to 60 s because some of the specimens were macroscopically clean after this time. Through the random allocation of the roots, the five treatment groups were well matched. The digital contrast program to identify calculus on the root surfaces has several advantages [27]. However, it fails to identify plaque because it is carried out without preliminary staining of all deposited material. Taking into account that plaque was not quantified, the cleaning ability of the Cavitron® ultrasonic device might have been underestimated in the present study.

Conclusion

At lower power settings, a more favorable relation between cleaning ability, loss of dentine, and surface roughness was found. For the dental practitioner, the only measure for the efficacy of ultrasound is the removal of calculus. This might be most efficient at the maximum power level of the respective device. More attention should be paid to the damaging potential of ultrasonic scalers such as loss of dental hard tissues and surface roughness.

Conflict of interest The authors declare that they have no conflict of interest.

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